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Porous Pavement: Research; Development; and Demonstration

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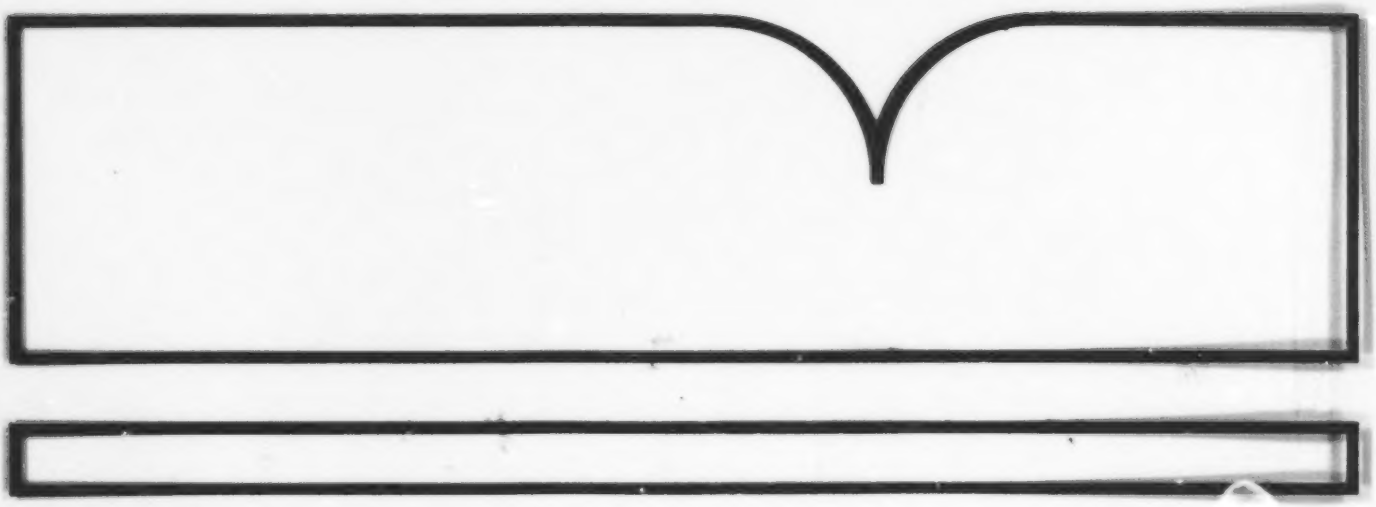
Edison, NJ

May 82



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16. ABSTRACT

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POROUS PAVEMENT: RESEARCH; DEVELOPMENT; AND DEMONSTRATION

By Richard Field,[1] Hugh Masters,[2] and Melvin Singer[3]

(Reviewed by the Highway Division)

ABSTRACT: This paper discusses the U.S. Environmental Protection Agency's porous pavement research program along with the economics, advantages, potential applications, and status and future research needs of porous pavements. Porous pavements are an available stormwater management technique which can be used on parking lots and low volume roadways to reduce both stormwater runoff volume and pollution. In addition, groundwater recharge is enhanced. Also, cost reductions result due to elimination of curbs, drains, and small sized storm sewers. Porous asphalt pavements consist of a relatively thin course of open graded asphalt mix over a deep base of large size crushed stones. Water can be stored in the crushed stone base until it can percolate into the subbase or drain laterally. Other porous pavement types include concrete lattice blocks and a porous concrete mix.

INTRODUCTION

With the extreme urban growth experienced in the United States over the last 30 years, environmental problems associated with urban land development have grown significantly serious. Specifically, the hydrology of a developing area is severely impacted. The installation of streets, parking lots, rooftops and storm sewers increases total volume of runoff and increases peak stream flows. Downstream flooding, stream in stability and endangering water quality, often result.

Realizing the effects of urbanization on the hydrological environment, many communities have passed laws encouraging land developers to practice sound storm-water management on their properties. In response, stormwater management methods, which maintain predevelopment or existing runoff levels, are being developed and implemented.

New approaches to stormwater management have focused primarily on detaining and retaining excess runoff on the site. Another alternative approach is

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to reduce the amount of impervious surfaces added to the site and, therefore, reduce the generation of excess runoff. An available technique for this nongeneration approach is the utilization of porous pavements for parking lots and low traffic volume roadways as demonstrated by Figs. 1 and 2.

Applications and research currently have concentrated on the use of asphalt and concrete porous pavement for parking lots. Expanded use of porous

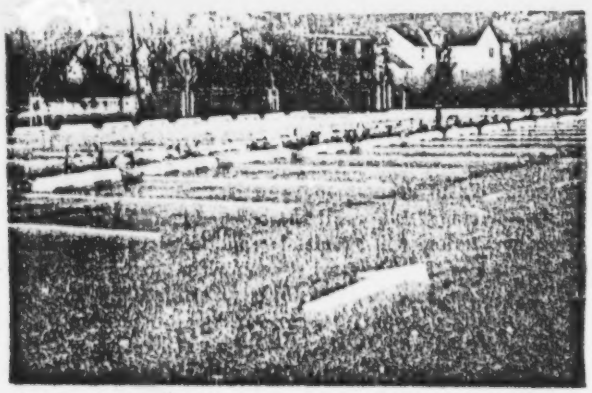


FIG. 1.—Porous Pavement (Asphalt)

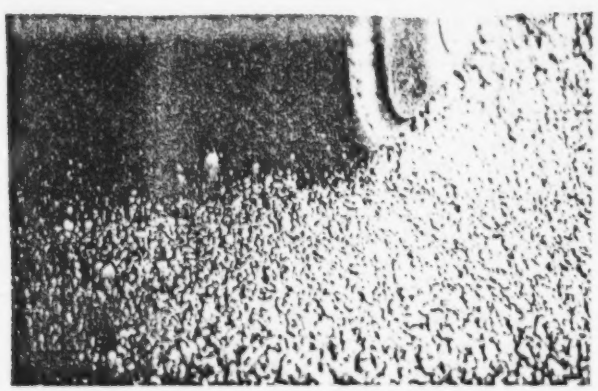


FIG. 2.—Porous Pavement (Asphalt)

pavements for parking lots and secondary roadways will require the collection of more data, further defining hydrological characteristics, water quality impacts, greater definitions of operation and maintenance during and after installation, and its service life versus that of conventional pavements. It is anticipated that continual and anticipated research by our program and others will provide much of this required information.

Stormwater Management Approaches

Urbanization has a profound impact on the hydrology of the area. Two principal factors account for this impact: the percentage of area made impervious through urbanization, and the land served by storm sewers. Traditionally, the goal of a stormwater management system has been to collect, transport and dispose of stormwater as efficiently and quickly as possible. Runoff generated is usually conveyed directly to storm sewers, draining more rapidly than from areas previously covered by natural vegetation.

This method of stormwater management has major effects on the hydrology of a developing area. First, it increases peak runoff. In addition, peak velocities are increased and lag time (the interval between precipitation and resultant runoff) is reduced. Finally, water quality is degraded.

An increase in peak flow can have a number of impacts downstream. First, as the stream attempts to accommodate the increase in volume and velocity of stormwater, it will lose stability. Stream bed and bank erosion with associated downstream sedimentation will result. Secondly, increased peak flows will increase the frequency of flooding downstream. This flooding can cause extensive economic loss, inconvenience, and possibly loss of life.

The increase in total runoff and the decrease in lag time results in less ground water recharge. This reduction in recharge ultimately results in decreased flows into stream channels. Therefore, urbanization not only increases flood peaks during storms, but it also decreases stream flow levels between storms. This greatly reduces the variety of life inhabiting a stream and can result in a negative water quality impact.

New Direction in Stormwater Management Practice

In response to downstream flooding problems, many communities have enacted legislation directing land developers to reduce the excess runoff associated with land development. This legislation, in turn, has caused a redefinition of stormwater management goals and has fostered the development and use of new stormwater management methods. The goals of innovative stormwater management are quite different from the goals of traditional stormwater management. Past practices have emphasized the quick elimination of stormwater. In contrast, the goals of innovative stormwater management are to maintain natural runoff levels by providing opportunities for infiltration, controlling velocity, extending lag time, and reducing runoff volume.

Current directions emphasize the maintenance of pre-development runoff levels through on-site controls. Where traditional stormwater management has utilized curbs and gutters to quickly convey stormwater to storm sewers, new approaches use roadside drainage swales to slow drainage and allow for infiltration. New techniques emphasize using natural drainage systems, with their low velocity flow characteristics, and taking advantage of opportunities for ground water recharge. Conventionally, rooftops, and parking lots have been designed to drain quickly. New goals encourage the ponding of stormwater on roof-tops and parking lots to provide temporary storage and slow-release of stormwater. In contrast to past practice, developers construct retention and detention structures which keep stormwater on site. Temporary storage may be provided in drainage swales

and depressions. Therefore, stormwater can be detained and allowed to either infiltrate into the soil or be slowly released after the storm.

Porous pavements have potential as a technology for maintaining predevelopment runoff levels by allowing for infiltration and ground water recharge. By acting as an attenuation and runoff reduction device, these pavements can decrease the volume and peak flow rate and increase lag time. This would minimize stream bank erosion and sedimentation due to increased runoff loads during and after storms, thereby reducing pollutant loads from erosion and land surface runoff. Thus, the use of porous pavements shows promise as an effective stormwater management device.

From a conventional standpoint, porous asphalt pavements have been used in regular applications for highway and airport runway construction. This open graded asphalt concrete mix has variously been referred to as plant mix seal coat, open graded mix, gap graded mix, popcorn mix, or porous friction course. This material consists of an open graded asphalt concrete mixture with a high percentage by weight of aggregate larger than a number four sieve which has a 0.187 in. (4.76 mm) aperture. The material is laid to a thickness of 0.75–1 in. (19–25 mm). The resulting pavement has a coarse surface texture (see Fig. 2) and a high percentage of void space. The coarse surface texture provides pressure relief channels to remove water under excess pressure between the pavement and a vehicle tire. Temporary storage is minimal here as the rainfall is diverted into nearby storm drains. The high percentage of void space also provides channels for dissipation of pressure and flow beneath the vehicle tire. Consequently, hydrostatic pressure cannot build up in the film of surface water under a vehicle tire, and potential hydroplaning is eliminated. Thus, the coefficient of friction between the tire and pavement is almost equivalent to the coefficient under dry conditions.

The highway departments of California, Nevada, New Mexico, Utah, and Louisiana, among others, have been using plant mix seal coats because of their safety aspects for at least the past 10 years. Application of this material to airport runways was initiated in 1967 at Farnborough, England (4) by the British Royal Air Force, and at two European air fields by the United States Air Force. Since 1947, the California Highway Department (3) has utilized roads with open graded base courses under conventional top paving to provide rapid drainage in problem areas.

U.S. Environmental Protection Agency's Porous Pavement Research

The Franklin Institute Research Laboratories (6), under Environmental Protection Agency (EPA) sponsorship, investigated the use of a porous base and a porous subbase in conjunction with a thicker application of the plant mix seal coat. The intent of this experiment was to investigate the potential of delivering water to the subbase rather than removing it to a stormwater collection system. They also evaluated a variety of conventional and unconventional materials. The most promising ones were tested to determine their physical and economic feasibility as porous pavement materials. Of those tested, the open-graded asphalt concrete was selected as the most suitable material because of its superior physical characteristics, its low cost, and its ability to be laid by conventional paving methods. Other porous pavement types studied included

various types of concrete lattice blocks (Figs. 3, 4 and 5).

An economic analysis undertaken during this study, determined by pavement type, the cost of porous asphalt in relation to conventional pavements with storm sewers, the relative value and market for the identified benefits of porous pavement, and the annual demand for the pavement types considered. Cost estimates for porous asphaltic were based on Asphalt Institute specification, which assumed the minimum base reservoir capacity of 16 in. (41 mm) that would be required in a medium precipitation area like Philadelphia. The results also assumed an average winter frost penetration level. Where the total thickness of surface and base exceeded conventional pavement thickness, an allowance was made for extra excavation costs. In areas of higher or lower precipitation, the cost of porous asphaltic concrete construction would be correspondingly increased or decreased somewhat, because of changes in required base reservoir capacity. Similarly, in areas of heavy frost susceptibility deep gravel bases normally are required to prevent freeze-thaw heaving, and the cost of porous construction would be correspondingly more favorable.

The results of the 1972 economic analysis are summarized in Table 1. In most cases, this study found the cost of conventional pavement with storm sewers to be higher than the cost of an equivalent porous asphalt installation without storm sewer relief. However, installations will have to consider the need for some storm sewer relief, until more field data on porous pavements is available. The economics of porous pavements are site specific since they are governed by design difference, the cost and proximity to the supply of stones and gravel, and the permeability of the adjacent soil. Therefore, each user will be required to do his own economic evaluation when considering the installation of porous pavements.

Initial porous pavement installations in Delaware and Pennsylvania (9) proved successful on a structural and drainage basis. Subsequent installations in The Woodlands, Texas (2), and Rochester, New York (5) were scientifically instrumented and monitored to provide greater information on both the pavements benefits and drawbacks. The Rochester results are reviewed later in this text.

Currently, each porous pavement design is unique, so it is evaluated and permitted by regulatory agencies only after a long analysis and review period. EPA, in a cooperative agreement with the City of Austin, Texas (1), hopes to standardize the design approach, yet allow the designer sufficient latitude for individual creativity. It is expected that the data from this project may be sufficient for standardizing the design of parking areas and residential streets. However, for complex conditions, a thorough analysis by qualified professionals is essential for the design of a porous pavement.

In general, potential as well as existing users and review agencies have expressed a need for data on three conditions regarding porous pavement systems. These conditions are:

1. Construction feasibility, maintenance and design life.
2. Control and management of runoff peak and volumes.
3. Control and management of water quality degradation.

The need to evaluate the runoff changes and water quality constituent changes from urbanizing activities is paramount in the design of porous pavement systems.

FIG. 3.—Porous Pavement (Concrete Lattice)

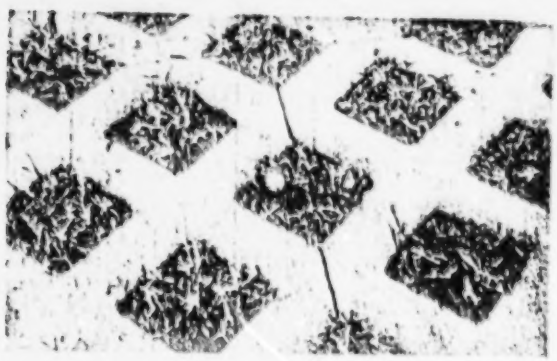


FIG. 4.—Porous Pavement (Concrete Lattice)

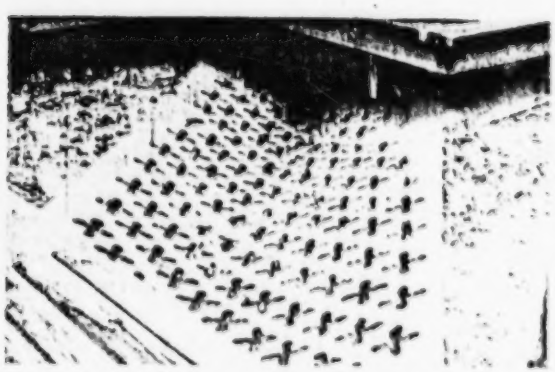


FIG. 5.—Porous Pavement [Grasscrete (TM)]

Unfortunately, most engineering practice still holds to the view that all pavements have to be evaluated solely from a runoff viewpoint. Only recently has water quality degradation become a point of concern for most practitioners and public

TABLE 1.—Porous Pavement Benefits 1972 Costs

Type of pavement (1)	Annual demand, in thousands of square yards (thousands of square meters) (2)	Conventional pavement with drainage, in dollars per square yards (dollars per square meters) (3)	Porous pavement, in dollars per square yards (dollars per square meters) (4)	Combined-Sewer Relief		Water Supply	
				Gross demand affected, in percentages (5)	Added value, in dollars per square yards (dollars per square meters) (6)	Gross demand affected, in percentages (7)	Added value, in dollars per square yards (dollars per square meters) (8)
Parking lot	45,986 (38,444)	4.73 (5.66)	6.36 (7.61)	18	5.54 (6.63)	24	0.15–0.42 (0.18–0.50)
Residential street							
low-design	133,425 (111,543)	7.20 (8.61)	6.35 (7.60)	18	5.54 (6.63)	24	0.29–0.83 (0.35–0.99)
high-design	12,129 (10,140)	10.23 (12.24)	6.38 (7.63)	18	5.54 (6.63)	24	0.32–0.92 (0.38–1.10)
Business street							
suburban development	32,547 (43,929)	8.40 (10.05)	6.38 (7.63)	18	5.54 (6.63)	24	0.29–0.83 (0.35–0.99)
city	4,776 (3,993)	18.20 (21.77)	7.66 (9.16)	18	5.54 (6.63)	24	0.32–0.83 (0.35–0.99)
County road							
low-volume	193,628 (161,873)	9.20 (11.05)	6.44 (7.70)	18	5.54 (6.63)	24	0.29–0.83 (0.35–0.99)
moderate-volume	203,864 (170,430)				5.54 (6.63)	24	0.33–0.84 (0.39–1.05)
Highway							
two-lane	141,955 (118,674)	14.50 (17.34)	7.36 (8.80)	18	5.54 (6.63)	24	0.33–0.84 (0.39–1.05)
four-lane							
asphalt	104,023 (86,963)	23.88 (28.56)	8.48 (10.14)	18	5.54 (6.63)	24	0.33–0.84 (0.39–1.05)
concrete		25.83 (30.90)	8.64 (10.33)	18	5.54 (6.63)	24	0.39–1.12 (0.47–1.34)
Playground	4,397 (3,676)	4.55 (5.44)	6.34 (7.58)				

officials. It is anticipated that as the concern for water quality of urban runoff becomes recognized, the need for porous pavement parking systems will increase.

Porous Pavement Hydrological Design Philosophy

When developing the design of a given porous pavement, the design storm runoff conditions, contributing area and soil infiltration rate will determine the

storage volume required for the reservoir base (Figs. 6 and 7). The selection of the design storm runoff conditions is dependent upon local desires and meteorological phenomenon.

The characteristics of the drainage basin including permeability of the soil, topography, and climate will impact the volume and rate of runoff and flow through the porous pavement and existing subsurface soil. Storage capacity, however, can be limited due to physical and economic limitations. Therefore

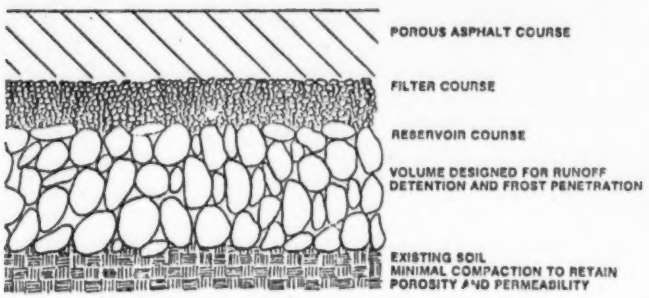

POROUS ASPHALT COURSE
FILTER COURSE
RESERVOIR COURSE
VOLUME DESIGNED FOR RUNOFF DETENTION AND FROST PENETRATION
EXISTING SOIL
MINIMAL COMPACTION TO RETAIN POROSITY AND PERMEABILITY

FIG. 6.—Porous Asphalt Paving Typical Section

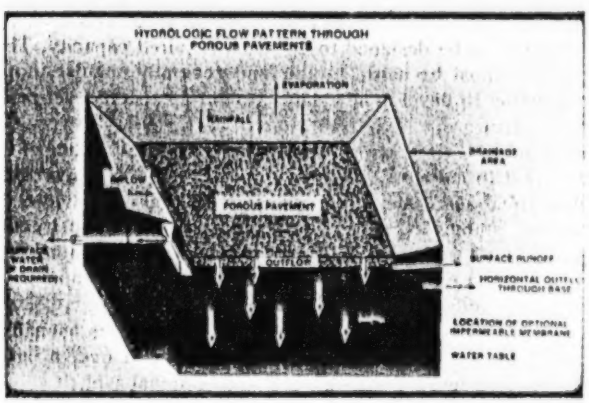


FIG. 7.—Hydrologic Flow Pattern Through Porous Pavements

relief measures, such as drain lines (with a smaller diameter than required for conventional pavement) should be incorporated into the system to prevent negative impacts that could develop such as flooding, freezing, anaerobic, or septic conditions.

The considerations examined here will result in a design for porous pavements. This design, which was adapted from Thelen and Howe (7) (Fig. 7) is as follows:

Subbase.—All soils under roads may become wet, but they must drain in order to maintain their bearing strength. Because soils under porous pavement

will get wet, they must be water permeable; they must not heave due to freezing or thawing, and they must not swell or substantially lose their strength when wet. Most soils can meet these requirements if proper drainage is available. In current practice it is important that the subbase under conventional pavement remain dry and the subbase often may be wet due to cracks in the pavement, percolation through the shoulders, and capillarity from the ground water. However, base strength is essentially retained because free water can drain away, leaving the soil particle structure intact.

Reservoir Base Course.—Conventional pavement has a base which consists of stones, sand, and dust particles packed into a dense mass, and is designed to transmit mechanical loads from the hardtop to the soil below.

Porous pavement, though, has a base which consists of large-sized and graded stones, lightly rolled into an open, interlocking structure which not only transmits mechanical loads, but also stores runoff water which the soil cannot immediately absorb. This water is held in the reservoir formed by voids in the rock matrix until it can percolate into the soil. These voids can be as high as 40% of the total volume. If the soil has a higher permeability rate than the rate of rainfall, then a reservoir is not needed.

The aim of having a reservoir is to store runoff water long enough to allow it to percolate into the soil. On sloping pavements, base areas at the higher end of the site are not credited with storage capability because they drain laterally and do not contribute to the percolation system.

Since the base reservoir serves a purpose similar to detention basins, runoff from roofs or other impervious and pervious surfaces could be drained into it; but the base must be designed to have the required capacity. The aggregate used in the base must be hard, durable and generally angular, not round, for proper compaction to develop adequate structural capacity, yet retain an open interlocking structure.

Reservoir Top Stabilizing Course.—Assisting in the final grading of the reservoir base course, and to stabilize the surface, a 2 in. (57 mm) layer of 0.5 in. (13 mm) crushed stone aggregate is recommended. Based on previous construction experience, this stabilizer course is necessary because construction vehicles hauling the asphalt hot mix across the reservoir course would create ruts which consequently require constant regarding to finished grade immediately prior to application of the hot mix.

Open Graded Asphalt Concrete Surface Course.—Porous asphalt consists of a wearing course of open graded asphalt concrete laid over a base course of uniformly sized aggregate. It differs from conventional asphalt concrete chiefly because it contains little dust or sand. The void volume, of porous asphalt, typically is around 16%, as compared with the 2–3% void volume of conventional asphalt concrete.

Asphalts used in asphalt concrete range from a 50–100 penetration grade, depending upon the ambient temperatures and viscosity characteristics desired. Generally, the grades used in a given locality for conventional asphalt concretes will suffice for porous asphalt as well. However, the porous product is more subject to scuffing, which occurs when the front wheels of stationary cars, with power steering, are turned. It is therefore suggested by Franklin Institute Research Laboratories that for porous asphalt, a 50–60% penetration grade be used in the South (Texas, and Florida, for example), a 66–80% in the mid-Atlantic

states, and an 85–100% penetration grade in the northern states.

The percent of asphalt should be specified between 5.5 and 6, based on the total weight of the pavement. The lower limit is to assure adequately thick layers of asphalt around the stones and the upper limit is to prevent the mix from draining asphalt during transport, particularly if it is accidentally shipped at a temperature of over 300° Fahrenheit (149° C).

To avoid damage due to photo-oxidative degradation of the asphalt (since air and sunlight can penetrate further), the asphalt coatings on the aggregate

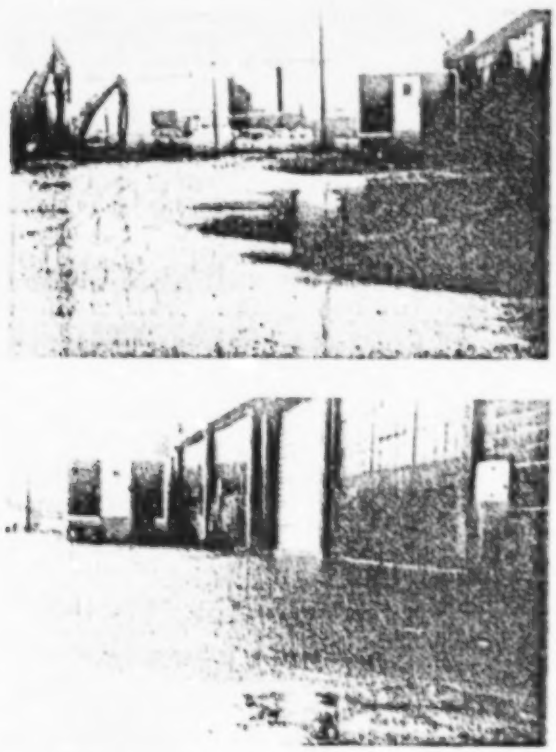


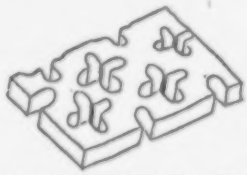
FIG. 8.—Lake Avenue Porous Pavement Site, Rochester, N.Y.

surfaces should be thicker than usual. In this case, the asphalt can form skins or otherwise be mildly degraded without significant loss of cementing properties.

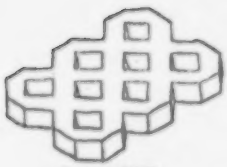
The open graded asphalt concrete is similar in Marshall properties (strength and flow) to conventional asphalt concrete. Thus, the usual thickness of base course and paving should satisfy load requirements. The base course thickness may have to be increased to provide greater reservoir capacity where runoff volumes, soil percolation, or both require it.

EPA Porous Pavement Demonstrations

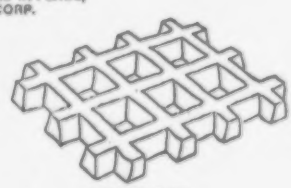
Rochester, New York (5).—Two parking lot sites were selected to demonstrate the effectiveness of utilizing porous pavements to reduce the rate of stormwater runoff and to investigate the long-term structural integrity of such pavements under severe environmental conditions. One of these sites was selected to evaluate



"GRASSCRETE" (POURED IN PLACE)
BY BOMANITE CORP.

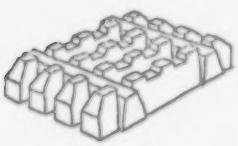


"TURFBLOCK"
PAVER SYSTEMS, INC.
WAUSAU TILE

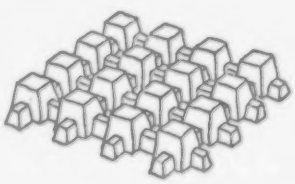


"GRASSTONE"
BOIARDI PRODS.

FIG. 9.—Concrete Porous Pavements—"Lattice" Type Pavers



"MONOSLAB"
GRASS PAVERS, LTD.



"CHECKER BLOCK"
HASTINGS CO.

FIG. 10.—Concrete Porous Pavements—"Castellated" Type Pavers

the structural integrity and permeability of the porous pavement under conditions of heavy truck traffic (Fig. 8).

Results of the study indicated:

1. Peak runoff rates were reduced by as much as 83%.
2. The pavement, which was subjected to 100 freeze and thaw cycles, showed no observable structural degradation. In addition, the water drained through the pavement without problems during the winter.

3. Through observations and flow monitoring, the structural integrity of the porous pavement installed, where heavy load vehicles were parked, was not impaired.

4. Clogging did result from runoff carrying a heavy sediment load. Clogging during the test study was relieved through cleaning by flushing.

5. The cost of constructing a porous pavement parking lot utilizing an impermeable membrane and underdrains was $\$18/yd^2$ ($\$21.5/m^2$), and is slightly higher than that of a conventionally paved lot with stormwater inlets and subsurface piping which is $\$16/yd^2$ ($\$19/m^2$). If subsurface soil conditions are adequate enough to allow passage of the rainfall that infiltrates through the porous pavement, then the impermeable membrane and underdrains are not needed and costs for both types of pavements would be the same.

Austin, Texas (1).—The overall objectives of this project are to demonstrate and evaluate the feasibility of using various porous pavement. The resulting information will be used to develop design criteria for potential porous pavement construction.

The first phase of this project has been completed and published in an EPA research report entitled, "Phase I—Design and Operational Criteria" (1). The objective of the work was to accumulate all available design, construction, and operational data for existing porous asphalt pavement areas. This report summarizes the data. Phase II of this project, which is still continuing, is comparing the runoff and water quality characteristics of porous pavements, which include porous asphalt pavement, and concrete lattice blocks (Figs. 9 and 10) to other kinds of conventional (asphalt, concrete, gravel, and grass) parking areas.

Advantages and Disadvantages of Porous Asphalt Pavement Usage

Advantages.—The primary objective of porous asphalt pavements for this program is to control runoff, and associated water quality degradation. Important benefits from porous asphalt pavements include:

1. Attenuation of the runoff rate and volume. The rate of flow reduction will reduce the need to rehabilitate undersized drainage system segments.
2. Improved erosion control.
3. Enhancement of water quality in areas where the runoff generated from impervious areas has the potential for becoming contaminated.

If the runoff pollutants are not toxic, and depending upon their characteristics, detention in the reservoir layer and percolation through the subbase may be sufficient to reduce the pollution to acceptable levels. If the stormwater requires treatment for toxic or nonfilterable substances, it may be stored in porous pavement systems, isolated from the natural ground, by an impermeable membrane until treatment plant capacity becomes available. Thus, treatment plant capacity does not need to be expanded and the volume and duration of storm and combined sewer overflows (CSO) are lessened. Detention of highly polluted initial runoff by the porous pavement, and dilution by less polluted subsequent runoff, can also result in acceptable pollutant concentrations throughout the storm duration.

4. A reduction or abatement in the need for curbs and storm sewer installation or expansion.

In areas relatively flat, rocky, or both, or with minimal soil depths, the cost of installing storm sewers is very high because both size and excavation volumes are increased, and excavation is made more difficult. The use of porous pavements in these areas reduces both sewer size and excavation depth, thus resulting in a net savings in drainage costs.

5. Retention of natural vegetation and drainage patterns.

6. Reduction or elimination of the nuisance factor to pedestrian and motorist arising from standing puddles and temporary storage in parking lots and streets.

7. Increase in the amount of ground water recharge to local aquifers in water defficient areas.

8. Improved road safety due to a higher friction coefficient, because of reduced hydroplanning and improved visibility.

Disadvantages.—The greatest concern with using porous pavement is its susceptibility to clogging. Based on past experience this problem should not occur if proper care and maintenance is taken. Erosion of surrounding soils cleared especially during construction should be alleviated, and clogged pavement can be cleared by flushing, and other street cleaning devices such as vacuums and brooms.

Porous pavement effectiveness has to be evaluated during the melting of ice and snow which has accumulated on its surface or if rain occurs when the subsurface is frozen. The test site in Rochester, New York (6) showed that this was not a problem.

Another disadvantage in the use of porous pavement results from the fact that some existing building codes and regulations are not intended for this new type of technology. Specifically, if conventional drainage structures (curbs, gutters, inlets) are arbitrarily required in all parking areas, then the construction costs of porous pavement installation become less economically attractive.

A temporary drawback arises out of a lack of data to indicate the capabilities of porous pavement and underlying soils to filter and purify contaminants in runoff. Results could lead to more subsurface pollution.

Spillage of gasoline from leaking tanks of automobiles parked on the porous pavement lot will break down the asphalt binder to greater depths than on conventional pavements, primarily because the pores on the open graded mix permit greater gasoline penetration. The solution to this problem may be the use of tar binders rather than asphalt.

Porous pavement is a multi-benefit strategy for pollution and flood control versus other more expensive downstream control strategies. The advantages, however, appear to outweigh the disadvantages. Consequently, the potential for porous pavement usage is expected to increase as the problems outlined in this section are resolved.

Summary

Porous pavements can be an effective means of reducing the increase in runoff rates and volumes, and water quality degradation, resulting from urbanization, or other land use changes. The design of porous pavements has to be undertaken with extreme care, particularly in areas where the natural soils do not have sufficient permeability to naturally drain the stored runoff within a reasonable time.

The use of porous pavements is presently limited to parking lots (due to the lack of structural data). Because all runoff from the site as well as adjacent areas draining into the site are effectively retained, the entire area contributing to the porous pavement has been removed from the surface hydrologic regime or retained in the system to permit downstream facilities to treat the stormwater flow. Consequently, the increase in runoff rates and volumes by urbanization is offset by a reduction in impervious areas.

The net downstream effect of porous pavements can range anywhere from a reduction of runoff rates and volumes, to below natural levels, or to the total elimination of runoff from the immediate area. In either case, the net effect downstream can be of significant benefit; in the case of storm sewers, the sewer requirements may be reduced or eliminated, thereby providing substantial cost reductions; and in the case of combined sewers, the number of overflows will be reduced or eliminated, directly benefiting the receiving water. In both cases, the cost of additional drainage facilities is reduced, and consequently, the incremental additional cost of porous pavement systems may be recovered.

The water quality of urban runoff has been shown to be severely polluted in some instances, but in all instances the runoff is at least partly contaminated. Obviously the infiltration and velocity reductions in porous pavements will result in some suspended particulate removal and some chemical pollutant reduction. The removal of water from the surface runoff regime prevents both the introduction of pollutants into the receiving water, and problems created by it in downstream areas.

When the possibility exists, that water infiltrating into the ground could reach a water supply aquifer, adequate precautions should be taken to determine that the surface runoff is not still contaminated when it reaches the aquifer. If there is a possibility of adversely affecting the aquifer, the porous pavement area should be designed to be sealed off from the aquifer recharge zone or should not be installed there.

Future Requirements of Program

The design of porous pavement parking lots is just emerging from the experimental phase. Most porous pavement users and designers would agree that further research and test demonstration pavement areas must be installed. Although existing porous pavements have performed more than adequately and have required minimal maintenance, some questions still remain. These include quantification of runoff and water quality changes, the long-term effects of continuous saturation of the subgrade, maintenance and cleaning requirements, and potential for plugging. Operation in snow, ice, and frozen ground conditions, aggregate gradation and asphalt content in the hot mix, construction material types and configurations, regulations and design requirements and the economic efficiency of using this type of pavement under existing regulations, are other issues which arise with the use of porous pavement.

Instrumented porous pavement systems in the future would be desirable. This instrumentation should provide information on rainfall, drainage, soil moisture, and water quality effects. The data provided should be continuous during the progress of a storm and through the soil profile, thus allowing an evaluation of dynamic changes in runoff and water quality. Toward this end, a detailed

analysis is being undertaken by EPA in the Austin, Texas (1) study. This work includes the evaluation of porous pavement and comparison to various other pavement types. The data to be collected should prove helpful in identifying the drainage and water quality benefits to be derived by porous pavements for a variety of rainfall events. Present unpredictable problems may be uncovered from this analysis.

Appendix.—References

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